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Economic Evaluation Methodology

By Frank A. Peters

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By Frank A. Peters

UNITED STATES DEPARTMENT OF THE INTERIOR
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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Btu	British thermal unit	h	hour
cal/g-deg K	calorie per gram-degree Kelvin	kW•h	kilowatt hour
°C	degree Celsius	lb	pound
DPW	day per week	Mgal	thousand gallons
d/yr	day per year	MMBtu	million British thermal units
°F	degree Fahrenheit	pct	percent
ft	foot	st	short ton
gal	gallon	yr	year

ECONOMIC EVALUATION METHODOLOGY

By Frank A. Peters[1]

ABSTRACT

This description of process evaluation techniques used by the Bureau of Mines for studying proposed processing techniques has been prepared to provide those interested in using these studies with an understanding of the methodology. The methods used for preparing both capital and operating cost estimates are described. Each step in preparing the evaluations is described. Types of equipment costs are shown and factors used in the estimates are defined. Uses of the estimates are suggested and several examples are included. The accuracy of various types of estimates is discussed, along with an explanation of the reason for selecting the type used in the Bureau's process evaluation studies.

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INTRODUCTION

The role of process evaluation in the Bureau of Mines research is twofold. Its primary function is to provide additional information for guiding the research programs, with a secondary function of aiding technology transfer to industry. This report describes evaluation techniques used by the Bureau for those interested in using the studies. Thus, both Bureau researchers and the general public will have an understanding of the estimating accuracy, how to modify the estimated costs, and the use of the evaluations.

In conducting research programs, process evaluations are performed in the early stages of research. Raw data from laboratory and bench-scale research are extrapolated to provide a basis for designing industrial-scale operations. Next, preliminary capital and operating costs for each operation are estimated. From this information, specific steps in the operations can be targeted for additional research, and plans can be modified to examine these areas in greater detail. After additional research is conducted, additional process evaluations are performed to provide further guidance. With repeated interaction and feedback between research and process evaluation personnel, the Bureau's research is focussed on areas critical to development of economically and technically feasible processes.

The Process Evaluation group examines the research from a varied and detached perspective. Each technology under investigation is projected from a laboratory scale to a commercial-plant scale. Problems and their solutions become more apparent from this perspective. In addition, engineers working in process evaluation are familiar with a broad range of technologies spanning the minerals industry; therefore, modifications or alternate technologies that might have been overlooked are frequently suggested.

Various types of information, vital in developing viable solutions to mineral problems, are presented in each evaluation. By examining individual processing steps, high-cost operations are determined and then investigated by research personnel to devise process modifications to reduce the cost of these operations. Process evaluation studies also identify and rank in importance areas in which additional research data are needed, both from a technical and a cost standpoint. In addition, performing process evaluations allows process variations to be compared and their relative worth assessed. Both similar and dissimilar operations can be contrasted, using cost as a common denominator.

Process costs are the primary means of comparing competitive technologies. Therefore, the availability of this information makes the research accomplishments more useful to industry and speeds their adoption. To aid technology transfer to industry, economic evaluations are published independently or included in publications describing the research.

ESTIMATING ACCURACY

The accuracy of cost estimates is difficult to define because there are a large number of unknowns; for example, the accuracy of the laboratory data and of the scale-up techniques. Materials often behave differently on a laboratory scale than they do on a commercial-plant scale, otherwise, pilot plants would not be needed. Thus, the incomplete data from laboratory investigations and the scale-up problems introduce potential errors in the cost analysis. Another important factor is the accuracy of the cost data and the costing techniques used in the studies.

Unfortunately, cost estimation is an art, not a science. No two estimators arrive at exactly the same results. The results depend as much on the skill of the estimator as on the technique used.

In an effort to define the accuracy of the estimate, many engineers compare their evaluation techniques with published outlines. Perhaps the most widely used reference is published in the Chemical Engineers' Handbook (1).[2]

The five capital cost estimating types and their accuracy percents are--

1. Firm, ±5%
2. Project control, ±10%
3. Budget, ±20%
4. Study, ±30%
5. Order-of-magnitude, no assigned accuracy.

A firm estimate is the most accurate and is based on final drawings, detailed equipment specifications, price quotations, and site surveys. Project control estimates are based on complete equipment lists, engineering flowsheets, and equipment layouts. Site-specific information and auxiliary facilities information are required. A budget estimate requires more information than a study estimate and, with sufficient data, its accuracy may approach that of a project control estimate. It requires a carefully evaluated flowsheet, a detailed equipment list, and site information. Study estimates are prepared from a flowsheet and a minimum of equipment data. Other costs are determined using factors. Order-of-magnitude estimates, the least accurate of the five types, are prepared without a flowsheet or a detailed list of equipment. Often, the estimate is prepared by comparing the proposed process with a known one.

Because Bureau estimates are prepared during laboratory research, insufficient data are available for making the detailed calculations necessary for a budget-type estimate. Thus, the study-type estimate was selected as the method that could most benefit the Bureau's program. This estimate can be expected to be within 30 pct of the actual plant cost. However, recent studies on first-of-a-kind plants show that this accuracy prediction is deceptive. Changes in the process, resulting from additional research studies, will probably require that the evaluation be updated as more information becomes available.

Cost estimators do not attempt to define the accuracy of operating cost estimates on a general basis. However, an inspection of the operating cost items, together with an estimate of the accuracy of each one, permits an estimation of the overall operating cost accuracy. Each raw material, utility, labor, and capital cost item must be considered. Obviously, when working from data reported in the literature, as occurs in many evaluations, it is almost impossible to define the accuracy of some of the data and thus is very difficult to determine the accuracy of the operating costs. However, if the various utility and labor rates are adjusted for location, it is unlikely that the operating cost will vary by more than 10 or 15 pct.

Calculations using data obtained in the laboratory and from the literature are used in the cost studies. Factors derived from other cost estimates and recommended values obtained from the literature are also used. In preparing the estimates, plant site or location is not considered; however, considerations such as nearness to raw material supply are included. A general location is often selected so that area-specific air and wet-bulb temperatures can be included in heat calculations.

The tables reporting the results are prepared to allow any company or individual interested in the process to easily change factors, utility rates, labor rates, or raw material costs to obtain costs for a specific location and company.

[2]Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

EVALUATION TECHNIQUES

Because most Bureau of Mines process development is in the early laboratory or bench-scale research stage, a cost-estimating technique that requires little data is needed. Detailed estimates and equipment designs that a company would prepare before building a plant could not be made. Thus, a factoring technique is used. Equipment is sized using a minimum of engineering and cost-capacity data. Installation and other plant costs are developed from factors. An indepth discussion of factored cost-estimation techniques is published in the literature (2).

This type of capital cost estimate matches that of a study estimate (1), and is expected to have the same accuracy. The major steps for preparing an evaluation are shown in figure 1.

Before any calculations are started, it is necessary to determine what data are available from research or pilot-plant operations and from the literature. It must also be determined where a proposed process would fit into present-day practice.

A plant size for the proposed process is selected, depending on the size of the industry and present-day commercial plants. More than one plant size may be considered. Also, the raw material deposit must contain sufficient material to justify the selected plant size.

FLOWSHEET DEVELOPMENT

The first step in making an evaluation is to prepare a process flowsheet showing each major step. Usually, research personnel provide a flowsheet; however, it often lacks processing steps, such as size reduction of ore, which is necessary for a complete plant description.

After considering the data available for each step, the necessary assumptions for making material and heat balances are tabulated. Because most evaluations are based on small-scale laboratory work, the best type of equipment is selected for each operation. An example would be the selection of a filter, where the possibilities could include the pressure leaf, rotary vacuum, or plate and frame. Each of these filters would produce cakes with different moisture contents and washing efficiencies. Thus, the type of equipment that would be used in a commercial plant is considered before completing the material balance.

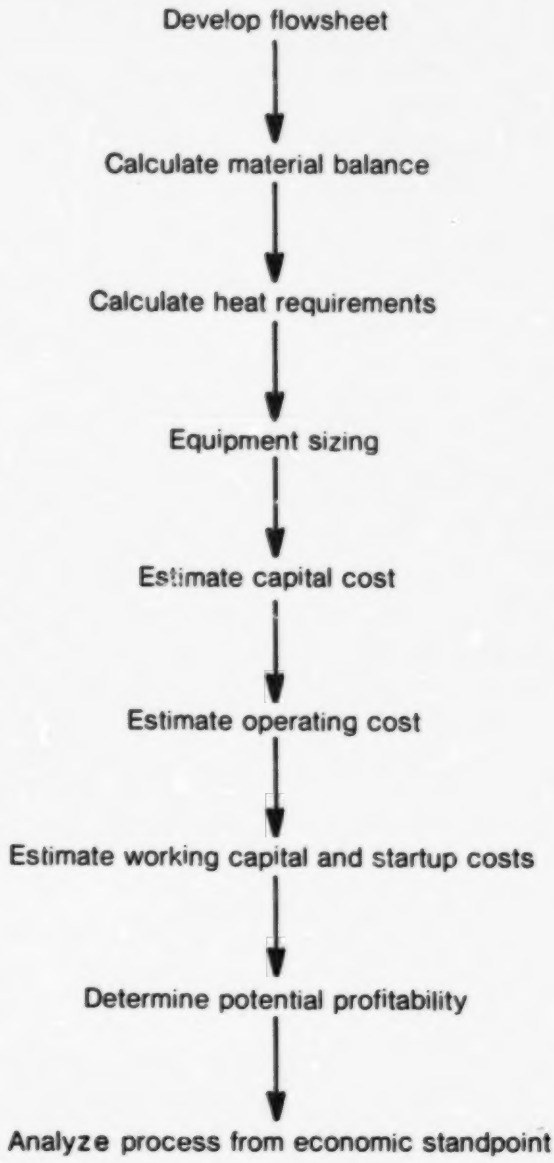

FIGURE 1.—Process evaluation steps.

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MATERIAL AND HEAT CALCULATIONS

The material balance is perhaps the most important part of the calculations, because all future calculations are based on flow rates and material requirements from the balance. Information left out of these calculations may have a significant effect on the process economics. The quantities of all materials entering and exiting each unit operation must be calculated. All components of each stream must be included so they can be accounted for in various chemical reactions. Many times, small quantities of impurities are not considered during research, but if they build up in recycle streams and are not treated, they may cause unexpected problems in plant-scale operations.

Some of the heat calculations must be made while making the material balances, but most are determined after the material balance is complete. Cooling a process stream by flashing steam or water vapor is an example of a heat calculation that must be made during material balance calculations, because the quantity of water lost would be controlled by the heat content of the process stream. All heat calculations are based on theoretical heats of formation and heat-capacity data. Laboratory heat usage is almost always much higher than plant requirements, because of the large surface area per unit volume of small equipment. Heat losses are estimated for various types and sizes of equipment. These estimated losses are based on values obtained from the literature and plant experience. Because of the extensive calculations required in making the heat calculations, a computer program is used that utilizes data from a table of heats of formation and heat capacity. An example of a heat calculation is shown in appendix A. As shown on the computer printout, heats of reaction are calculated at 25° C. The heat above or below 25° C entering the system in each stream and the heat leaving the system at the reaction temperature are calculated. Heat losses are estimated using experience factors for each type of equipment. The net heat needed or rejected by the system is then determined, and the quantity of fuel, steam, or cooling water is estimated.

EQUIPMENT SIZING

After completing the heat calculations, a commercial-size plant must be designed. The first step is to size major items of equipment, such as kilns, crushers, reaction vessels, etc. After determining the number and size of each major item, a rough equipment layout is prepared so that equipment for pumping, conveying, feeding etc., can be sized.

Sizing or designing of the major equipment items is performed by using techniques described in estimating manuals and textbooks, using manufacturers catalogs, or requesting size and cost quotations from manufacturers. When designing special equipment items, codes such as the ASME Boiler and Pressure Vessel Code (3) are used. However, detailed designs are seldom needed for equipment costing; for example, tanks are sized using the flow rate in tons or pounds per day, specific gravity, and retention time. Additional capacity is added when agitation is used. Conversely, crushing equipment requires considerable data. The work index, feed size, product size, maximum feed size, feed rate, bulk density, and excess capacity must be specified. Standard sizing techniques have been selected and programmed on personal computers to reduce calculation time for most of the common types of equipment.

To size minor equipment items such as surge bins, pumps, feeders, and conveyors, distances and heights must be estimated from the size and location of each major piece of equipment. Using flow rates from the material balance, together with the distances, heights, and material densities and viscosities, the pump or conveyor size and energy requirement for transporting the material can be estimated.

CAPITAL COSTS

Capital costs are divided between fixed capital, working capital, and capitalized startup.

Fixed Capital

After sizing the equipment, its cost must be estimated. Many types of equipment are costed using cost-capacity data shown in graphical form. A typical cost-capacity curve is shown in figure 2. An excellent description of the use of this type data is given by Peters and Timmerhaus (2).

Because most textbook cost data are old, new curves or equations must be developed from recent equipment costs. These costs are obtained from price quotations and published cost data. If the equipment is to be manufactured of a corrosion-resistant material, its cost must be adjusted using a factor or its cost obtained for the special material of construction.

Although the costs of most items are estimated from cost-capacity equations, the costs of unusual or very expensive items of equipment are obtained from vendors. Some equipment costs are also obtained from cost-estimation services such as Richardson (4) and the Mining Cost Service (5).

Because equipment costs change with time, the equipment cost is adjusted to the current date using an inflation index such as the Marshall and Swift (M and S) Equipment Cost index, which is found in alternate issues of Chemical Engineering. Equipment costs are tabulated in a table, such as shown in figure 3.

After estimating equipment costs, the next step is to estimate the cost of labor for erecting each piece of equipment. This cost includes removing the equipment from a truck, moving it to its plant location, setting it up, and aligning the item with a crane if necessary. Again, graphs or equations of labor time versus equipment size are used to estimate the number of person hours required. The equations have been developed from similar installations and data in the literature. The number of hours is multiplied by the average hourly wage for an erection crew. When equipment quotations are used, the vendor is asked for an estimate of the labor requirement for erection. When equipment is purchased on an erected basis, as with items such as silos and large storage tanks, it is unnecessary to estimate erection labor, because its cost is included in the equipment cost.

Equipment and erection labor costs represent less than half the cost of building a plant. Other items include foundations, buildings, structures, insulation, instrumentation, electrical installation, piping, and painting. To obtain these costs, the total uninstalled equipment cost is multiplied by a factor.

Factors based on the type of plant or operation, and material of construction, are used for estimating the costs of structures, insulation, instrumentation, piping, and painting for each plant section. They are obtained from the literature, nonpublished estimates, and through consultations with other engineering cost estimators. When the factors have been selected, they are entered in equipment cost summary tables for use in calculating equipment installation costs, as shown in figure 3.

Although most estimators use factors for foundations, electrical installation, and insulation, the Process Evaluation group has developed equations to estimate these costs separately for each piece of equipment. A factor is then calculated for each of these items.

Foundation costs are based on equipment weight, vibration effect, and typical soil loadings. For common items of equipment, the costs of concrete, reinforcing steel, and construction labor have been estimated for a range of

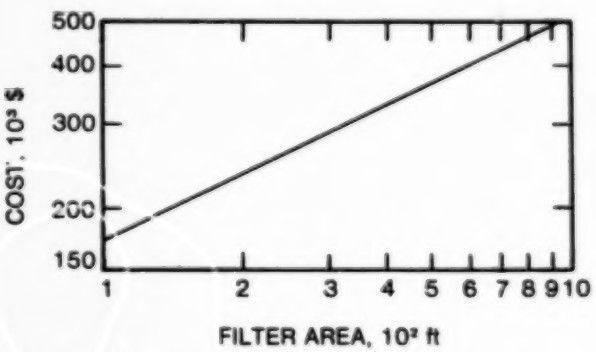

FIGURE 2.—Cost of horizontal vacuum belt filters, 2nd quarter 1986.

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TABLE _. - Equipment cost summary

Item	Equipment[1]	Labor	Total
_____.....	$	$	$
_____.....	_____	_____	_____
Total.....			_____

Total equipment cost x factor indicated:

Foundations, x _____.....	
Structures, x _____.....	
Instrumentation, x _____.....	
Electrical, x _____.....	
Piping, x _____.....	
Painting, x _____.....	
Miscellaneous, x _____.....	_____
Total.....	_____
Total direct cost.....	
Field indirect, 10 pct of total direct cost.....	_____
Total construction cost.....	
Engineering, 5 pct of total construction cost.....	
Administration and overhead, 5 pct of total construction cost.....	_____
Subtotal.....	
Contingency, 10 pct of above subtotal.....	_____
Subtotal.....	
Contractor's fee, 5 pct of above subtotal.....	_____
Section cost.....	

[1]Basis: M and S equipment cost index of _____.

FIGURE 3.—Equipment cost summary table format.

equipment sizes. The results of these calculations were used to prepare equations for estimating the cost of foundations for each piece of equipment. For nonstandard items of equipment, the foundations are designed separately, using standard engineering techniques.

The costs for installing the electrical work for each motor size have been estimated for typical plant conditions and are used in the plant cost estimates. The costs for wire, boxes, switchgear, labor, etc., were included in these standard designs.

Building costs for various types of buildings are estimated from square-foot costs. Design considerations include building height, type of construction, and use. Building sizes are based on the equipment layout prepared for each plant.

Depending on plant location, the estimator determines which equipment must be housed and which can be erected outside.

A miscellaneous factor of 5 to 10 pct, depending on the detail used in itemizing equipment, is added to each plant section to cover the cost of small items not separately listed.

Where a tailings pond or other disposal area is needed, its construction cost must be estimated and added to the capital cost.

After the direct costs are determined, the field indirect, engineering, administration and overhead, contingency, and contractor's fee are then estimated. Typical percentage values of these costs are shown in figure 3. Each of these components is defined in appendix B.

After preparing equipment cost summary tables for each plant section, the total section costs are tabulated in an estimated capital cost table, such as figure 4. Several other cost items are included in this table: a steamplant (if needed), plant facilities, plant utilities, and interest during construction. Percentage values used for plant facilities and plant utilities are shown in figure 4. Items included in plant facilities and

TABLE _. - Estimated capital cost[1]

Fixed capital:	
_____ section	$
_____ section	
Tailings pond	
Steamplant	_____
Subtotal	
Plant facilities, 10 pct of above subtotal	
Plant utilities, 12 pct of above subtotal	_____
Basic plant cost	
Catalyst	
Escalation costs during construction	_____
Total plant cost	
Land cost	_____
Subtotal	
Interest during construction period	_____
Fixed capital cost	
	_____
Working capital:	
Raw material and supplies	
Product and in-process inventory	
Accounts receivable	
Available cash	_____
Working capital cost	
Capitalized startup costs	_____
Subtotal	
	_____
Total capital cost	

[1]Basis: M and S equipment cost index of _____.

FIGURE 4.—Estimated capital cost table format.

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plant utilities are tabulated in appendix B. The steamplant size is based on the process steam requirements (quantities and pressure) plus an allowance for distribution losses.

The capital cost of a catalyst must also be included, and it must be depreciated in the operating cost if the original amount cannot be recovered. Many times an extractant or ion-exchange material must be considered in the same manner.

To allow for high inflation rates, such as occurred during the mid 1970's, a factor for inflation during construction may be included in the estimates. The costs of many equipment items are quoted on the basis of an index when delivered. Thus, a firm cost is unknown until the item is shipped. To compensate for this problem, an inflation factor equivalent to the current inflation rate is added to escalate the basic plant cost. During periods of low inflation, this item is not included in the estimates.

Although land cost is also included in the plant cost by many evaluators, the Bureau cost estimates do not include it since the plant location is not selected, and its cost can be recovered after closing the plant.

To determine the total fixed capital cost, the interest during construction is determined by calculating the interest payment for each month during the construction period. Because expenditures are not uniform, a curve (fig. 5) was developed to relate the expenditures to time (6). A value slightly less than the prime rate is normally used as the interest rate in the cost estimates.

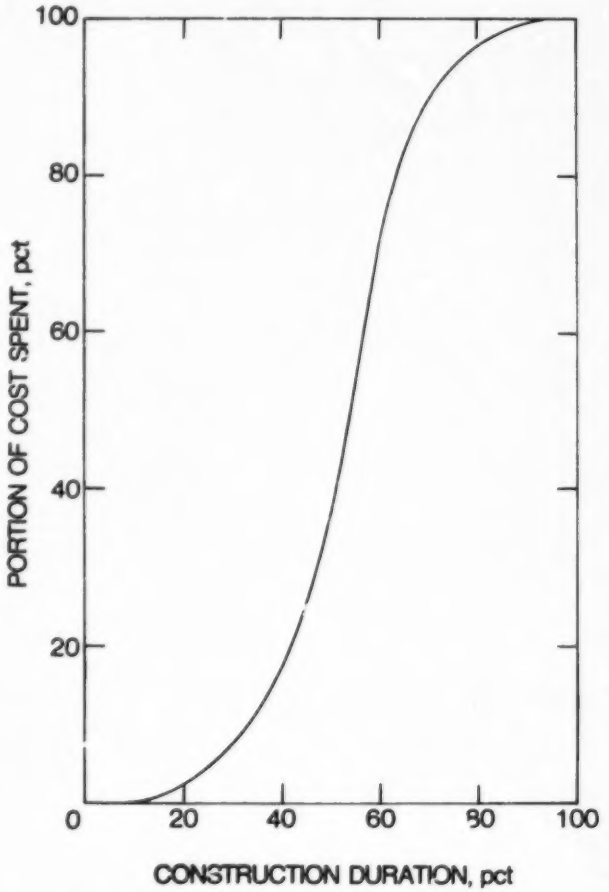

FIGURE 5.—Capital expenditure-time relation curve.

Working Capital

In addition to fixed capital, working capital is estimated and included in the total capital cost. These cost categories are also shown in figure 4. Working capital is defined as the funds in addition to fixed capital, land investment, and startup costs that must be provided to operate the plant. Working capital is normally estimated from the following items: (1) Raw material and supplies inventory, (cost of raw material and operating supplies for 30 days), (2) product and in-process inventory, (total operating cost for 30 days), (3) accounts receivable, (total operating cost for 30 days), and (4) available cash (direct expenses for 30 days). Although 30 days is used for calculating each of the previous items, this time period is adjusted when necessary; for example, if the mine that supplies the ore operates 6 months per year, the time period for raw materials and supplies inventory must be adjusted.

Capitalized Startup

Startup costs are also included in the cost studies. Usually, these are estimated as 10 pct of the fixed capital costs, of which 1 pct is capitalized and shown in the capital cost table. The

remaining 9 pct are assumed to be first-year operating costs; however, they are not included in the operating cost table, which represents a typical year. These startup costs are considered in the discounted cash-flow analysis. A 3-month startup period is usually considered, during which, the production level is assumed to average 50 pct of the design capacity.

OPERATING COSTS

A factoring technique is also used for estimating operating costs. For plants operating 3 shifts per day, 7 days per week, 330 to 350 d/yr of operation over the life of the plant is used for cost calculations. This allows downtime for inspection, maintenance, and unscheduled interruptions. When operating less than 3 shifts per day, 7 days per week, it is assumed that maintenance is performed outside of the normal operating period.

Operating costs are divided into direct, indirect, and fixed costs. Items included in operating components are shown in appendix C, and typical cost factors are shown as percentages in figure 6.

Direct

Direct costs include raw materials, utilities, direct labor, plant and equipment maintenance, payroll overhead, and operating supplies. Quantities of raw materials, which include reagents, are taken directly from the material balance. The cost for each raw material is taken from published prices or producer's quotations. Freight costs are usually included as part of each raw material cost when the plant location is specified. Ore cost is based on mining cost and sometimes includes a profit. Concentrate costs or values are based on smelter schedules.

Utilities include electricity, water, fuel, and steam. Electric power requirements are determined by calculating the actual power requirement needed for each piece of equipment before selecting the motor. The length of time each motor operates is included in the calculation. Electric power requirements for electrolytic cells, etc., are also added. Electric power requirements for lighting and air conditioning in offices, laboratories, and control rooms are estimated. These requirements are based on building type and size. The total electric power is then multiplied by the rate that would be expected in the area where the plant is built. The demand charge is included in the electric power rate.

Water requirements are divided into process and cooling water. The quantity of process water is based on the material balance plus make-up water for cooling towers and the steamplant. Because process water costs are normally small, average water costs are used instead of costs specific to plant location. Cooling water requirements are based on thermodynamic calculations. Depending on plant location, cooling water may be obtained from rivers, wells, or cooling towers. If towers are used, make-up water requirements are estimated.

Plant location, process requirements, and fuel costs (including freight) are considered when selecting the fuel to be used in each plant. Some operations, such as alumina calcination, require a special fuel such as natural gas or sulfur-free oil, while other operations can use any fuel. If process requirements do not dictate the choice, a cost comparison including equipment costs is made to select the least expensive fuel. In some plants, several fuels may be selected for different operations. Sometimes, it is even possible to use an offgas from a chemical operation as a fuel. Where steam is used for heating, it may be purchased from another operation or produced in a steamplant.

Direct labor cost is determined by multiplying the assigned operating positions by multipliers, depending on the days per week and shifts per day of the operation. These multipliers are shown in table 1. Supervision is estimated as 15 pct of the labor cost.

Plant maintenance is separately estimated for each piece of equipment and for buildings, electrical system, piping, utility-distribution systems, and plant facilities. This cost is divided evenly

TABLE _. - Estimated annual operating cost

	Annual cost	Cost per pound product
Direct cost:		
Raw materials:		
_____ at $__/st.....	$	$
_____ at $___/st.....		
____ at $__/lb.....		
Chemicals for steamplant water treatment.....		
Total.....		
Utilities:		
Electric power at $__/kW•h.....		
Process water at $__/Mgal.....		
Fuel oil at $__/gal.....		
Coal at $__/st.....		
Natural gas at $__/MMBtu.....		
Total.....		
Direct labor:		
Labor at $__/h.....		
Supervision, 15 pct of labor.....		
Total.....		
Plant maintenance:		
Labor.....		
Supervision, 20 pct of maintenance labor.....		
Materials.....		
Total.....		
Payroll overhead, 35 pct of above payroll.....		
Operating supplies, 20 pct of plant maintenance.....		
Royalty.....		
Total direct cost.....		
Indirect cost, 40 pct of direct labor and maintenance.....		
Fixed cost:		
Taxes, 1 pct of total plant cost.....		
Insurance, 1 pct of total plant cost...		
Depreciation, __-yr life.....		
Total operating cost.....		
Credit:		
_____ at $__/st.....		
Net operating cost.....		

FIGURE 6.—Estimated annual operating cost table format.

between labor and materials, with 20 pct of the labor cost added for supervision.

TABLE 1. - Multipliers for labor assignments

Days per week	Shifts per day	Multipliers
7.....	3	4.2
7.....	2	2.8
7.....	1	1.4
5.....	3	3.0
5.....	2	2.0
5.....	1	1.0

Payroll overhead, estimated as 30 to 35 pct of direct labor and maintenance labor, includes vacation, sick leave, social security, and fringe benefits. The cost of operating supplies is estimated as 10 to 20 pct of the cost of plant maintenance. Operating supplies include items such as filter cloth, lubricating oil, gasoline and diesel fuel, instrument charts, etc. The cost of grinding balls and rods are shown separately under raw materials, because they are not considered a supply item and are directly related to the abrasiveness of the ore.

Indirect

Indirect costs are estimated as 40 pct of the direct labor and maintenance costs. The indirect costs include the expenses of control laboratories, accounting, plant protection and safety, plant administration, marketing, and company overhead. Research and overall company administrative costs outside the plant are not included.

Fixed

Fixed costs include local taxes (excluding income taxes), insurance, and depreciation. Both taxes and insurance are estimated at 1 pct of the fixed capital cost. Depreciation is calculated on a straight-line basis using 10 to 20 yr depending on practice within the individual industry.

PROFITABILITY

Industry is primarily interested in potential profits in any venture. Thus, one must consider profitability in addition to capital and operating costs. Today, a number of techniques are used for estimating profitability. Many textbooks (7-9) contain discussions of the advantages and disadvantages of each calculation method.

Two of the more important techniques are used in the evaluations. The first is a simple payback period, which can be calculated from a selling price. The second is an interest rate of return based on a discounted cash-flow analysis. This technique considers the time-value of money, and compares the profits from a venture with the interest that would be earned if the capital were invested in a bank. The results of this discounted cash-flow analysis are presented as an interest rate of return when the selling price is known or the interest rate of return can be graphically presented to show the profits versus selling price.

USE OF ECONOMIC EVALUATIONS

Performing an economic evaluation is only the first step in developing a process evaluation. Economic data must be broken down to show high-cost operations, utilities, raw materials, etc. Additional data needs are identified, and alternate technologies are often suggested for some of the processing steps. The effect of changing costs must be considered to provide research personnel with information to help in developing a viable process.

The estimated capital and operating costs for each section are examined to

identify high costs. If a section cost appears high in relation to others and it contains a number of unit operations, the section is divided into two or more sections to identify the unit operation responsible for the high cost.

For example, a steam requirement for evaporation may be very high. In this situation, two possible solutions must be considered; (1) could the use of multi-effect evaporators reduce the steam requirement, and (2) can the quantity of water added to the process be reduced. Each addition of water must be checked to determine if it could be reduced. This step requires the comparison of each operation with similar commercial practices. If it appears that some of the water requirements could be reduced, it is suggested that research personnel investigate the possibility of using less water and request a new evaluation when minimum water requirements are determined.

Sometimes suggestions are made to change a step or group of steps in a process to reduce costs. Occasionally, using part of an existing process would be more economical. Often, the evaluation may only identify a costly step so that the researcher can replace or improve an operation. Thus, researchers know where to concentrate their efforts.

A major advantage of preparing an evaluation at early stages in a research investigation is to show where additional data are needed. Assumptions are identified in the process description and sometimes listed to provide additional guidance to the researchers.

Environmental problems are identified and solutions suggested where possible. Most researchers direct their attention to recovering the maximum quantity of the valuable minerals in an ore. They neglect the impurities and often do not obtain analyses for them. Because impurity information is needed when making a complete evaluation study, the information to identify potential environmental problems is available. Often these minor impurities can become a major disposal problem. If technology is available for solving a disposal problem, it is incorporated into the evaluation. If technology is not available, solutions are suggested where possible.

Disposal costs are estimated to determine how much money is available to treat the waste material. Using the cost of disposal as a basis, various techniques proposed by researchers and evaluators can be compared. Putting a lid on processing costs also helps to predict the overall viability of a proposed process.

To aid technology transfer to industry, some of the economic evaluations are published independently, while others are included in publications describing the research. This availability of process cost information permits industry to compare new technologies with those currently in use.

These evaluations provide industry with guidance when considering Bureau work; for example, there is a published process evaluation involving a process that recovers lead from scrap batteries (10). These published cost studies provide basic process requirements and cost data. Because the costs are presented in a format that is easy to revise, changes can be quickly made. Any company can revise the costs with new cost data to fit the company's conditions and modify the studies for its location and policy. Thus, it is very easy for company management to assess the potential of a Bureau development.

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APPENDIX A.--HEAT CALCULATIONS

A typical heat calculation output from a line printer is shown in figure A-1. The computer program was originally written for mainframe computers, but has been adapted for microcomputers. All uppercase letters are used for chemical compounds, thus $CaCO_3$ is shown as CACO3 in the printout. Solids are indicated as -S and liquids as -L to show the standard state of each compound.

Heats of reaction are calculated at 25° C using heat of formation data. Heat above 25° C in each entering stream is calculated and credited to the system. Heat leaving the system above 25° C is also calculated, and its requirement added to the system. The net heat is then calculated and shown as the gross heat requirement. Actual cooling water, fuel, or steam requirements are then calculated from this gross heat requirement after estimating heat losses for the type of equipment being used for the operation.

```
                                                DATE: 12/10/1986  TIME: 11:10:30  FILE: HT86009R
                                    MATERIAL BALANCE BASIS: 7 DP's, OPERATIONS: 3 SPD, 7 DP's

                                        HEAT OF REACTIONS

REFERENCE MATERIAL IS CAS-S                    WEIGHT IS      2250.000 TON       NO. OF MOLES IS  2
  2 CAS-S          +  1 (NH4)2CO3-AQ       +  1 H2CO3-AQ          +  0                    =
    2 CACO3-S        +  2 NH4HS-AQ           +  0                   +  0                    .

HEAT OF REACTION =     2250.000 X 2000.000 X     -375.7484 =  -0.1690886797E+10 BTU PER DAY
-----

TOTAL HEAT OF REACTIONS                                  =  -0.1690886797E+10 BTU PER DAY


                                          HEAT IN

CALCIUM SULPHIDE          IN  AT    66. DEG C (  151. DEG F)
     CAS-S                ---       2250.000 TON          =   0.5215531600E+08 BTU PER DAY          WCP=  0.157 CAL/G-DEG K
     OTHER                ---        428.600 TON          =   0.1207604400E+08 BTU PER DAY          WCP=  0.200 CAL/G-DEG K
          TOTAL                     2678.600 TON
   TOTAL HEAT IN  AT    66. DEG C (  151. DEG F)          =   0.6483135600E+08 BTU PER DAY
-----

AMMONIUM BICARBONATE      IN  AT    90. DEG C (  194. DEG F)
     (NH4)2CO3-AQ         ---       1495.400 TON          =   0.9072066400E+08 BTU PER DAY          WCP=  0.230 CAL/G-DEG K
     H2CO3-AQ             ---        967.200 TON          =   0.6714028800E+08 BTU PER DAY          WCP=  0.297 CAL/G-DEG K
     NH4OH-AQ             ---         54.700 TON          =   0.1352076108+08 BTU PER DAY           WCP=  1.056 CAL/G-DEG K
     NH4HS-AQ             ---        162.000 TON          =   0.2150913608+08 BTU PER DAY           WCP=  0.567 CAL/G-DEG K
     H2O-L                ---       8068.100 TON          =   0.1808636352E+10 BTU PER DAY          WCP=  0.999 CAL/G-DEG K
          TOTAL                    10750.000 TON
   TOTAL HEAT IN  AT    90. DEG C (  194. DEG F)          =   0.2069254408+10 BTU PER DAY
-----

TOTAL HEAT IN                                            =   0.2134045578+10 BTU PER DAY


                                         HEAT OUT

CARBONATED SLURRY         OUT AT   100. DEG C (  212. DEG F)
     CACO3-S              ---       3121.500 TON          =   0.1787672038+09 BTU PER DAY           WCP=  0.212 CAL/G-DEG K
     OTHER                ---        428.600 TON          =   0.2318787808+08 BTU PER DAY           WCP=  0.200 CAL/G-DEG K
     NH4HS-AQ             ---       1756.000 TON          =   0.2698174088+09 BTU PER DAY           WCP=  0.567 CAL/G-DEG K
     NH4OH-AQ             ---         54.700 TON          =   0.1568097808+08 BTU PER DAY           WCP=  1.056 CAL/G-DEG K
     H2O-L                ---       8068.100 TON          =   0.2176457318+10 BTU PER DAY           WCP=  0.999 CAL/G-DEG K
          TOTAL                    13428.900 TON
   TOTAL HEAT OUT AT   100. DEG C (  212. DEG F)          =   0.2668314658E+10 BTU PER DAY
-----

TOTAL HEAT OUT                                           =   0.2668314658E+10 BTU PER DAY


     TOTAL QUANTITY IN  =     13429.000 TON

     TOTAL QUANTITY OUT =     13428.900 TON

GROSS HEAT                                               =   -1161.807 => BTU PER DAY
```

Abbreviations used:

AQ	Aqueous	S	Solid
L	Liquid	SPD	Shift per day
MCP	Mean heat capacity		

NOTE.--"Ton " indicates short tons.

FIGURE A-1.—Example of heat calculation.

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APPENDIX B.--ITEMS INCLUDED IN CAPITAL COST COMPONENTS

Labor--Erection labor cost for setting equipment in place, which includes moving the equipment from its storage location.

Foundation--Material and labor cost for equipment or equipment support foundation.

Buildings--Process building costs for material and labor includes the following:

- Stairways
- Windows
- Elevators
- Plumbing
- Heating
- Ventilation
- Dust collection
- Air conditioning
- Sprinkler system
- Lighting
- Telephones
- Fire alarm
- Painting

Structures--Material and labor cost for equipment structures includes the following:

- Equipment supports
- Platforms
- Ladders
- Pipe supports

Insulation--Material and labor cost for insulation for equipment and piping.

Instrumentation--Instrumentation cost includes instruments, installation labor, and instrument panels.

Electrical--Material and labor cost for electrical includes the following:

- Wire
- Conduit
- Switches
- Panels

Piping--Material and labor cost for process piping includes the following:

- Pipe
- Pipe hangers
- Fittings
- Valves

Painting--Material and labor cost for painting equipment, piping, and equipment supports.

Miscellaneous--Cost of minor items of equipment not included in the process equipment list.

Field indirect--Construction expenses includes the following:

Construction, operation, and maintenance of temporary sheds, offices, roads, parking lots, railroads, electrical, piping, communications, and fencing.
Construction tools and equipment
Warehouse personnel and expense
Construction supervision
Accounting and timekeeping
Purchasing, expediting, and traffic
Safety and medical
Guards and security personnel
Travel and transportation allowance for craft labor
Housekeeping
Weather protection
Equipment rental (construction)
Permits, special licenses, field tests
Rental of off-site space
Fringe benefits
Interest
Taxes and insurance

Engineering--Cost includes the following:

Process engineering
Project engineering
General engineering
Drafting
Cost engineering
Reproductions
Scale model

Administrative and overhead--Cost includes the following:

Administrative
Procurement, expediting, and inspection
Travel and living expenses

Contingency--Compensation for unpredictable events, i.e.,

Storms
Floods
Strikes
Price changes
Small design changes
Errors in estimation
Unforeseen expenses

Contractor's fee--Contractor's home office expenses, fees, and profits.

Plant facilities--Material and labor cost includes the following:

Auxiliary buildings
    Administration offices
    Medical and dispensary

- Cafeteria
- Garage
- Parts or stores warehouse
- Maintenance shops
  - Electric
  - Piping
  - Sheet metal
  - Machine
  - Welding
  - Carpenters
  - Instrument
- Guard and safety
- Hose house
- Change house
- Personnel
- Smoking stations (in hazardous plants)
- Shipping office and platforms
- Control laboratories
- Fire-protection facilities
- Building services--same as those listed under process buildings

Nonprocess equipment

- Office furniture and equipment
- Cafeteria equipment
- Safety and medical equipment
- Shop equipment
- Automotive heavy maintenance equipment
- Yard material-handling equipment
- Laboratory equipment
- Lockers and locker-room benches
- Garage equipment
- Shelves and bins
- Housekeeping equipment
- Fire extinguishers, hoses, fire engines

Site development--if not included separately under site preparation

Plant utilities--Material and labor cost includes the following:

- Power-distribution system
- Water-distribution system
- Air-distribution system
- Refrigeration-distribution system
- Fuel-oil distribution system
- Gas-distribution system
- Process sewers
- Sanitary sewers
- Storm sewers
- Fireloops and hydrants
- Electric substations
- Compressed air plant--nonprocess
- Incinerator
- Ash disposal--if not included in process design
- Waste disposal--if not included in process design
- Wells
- River intake

Primary water treatment
    Filtration
    Coagulation
    Aeration
Secondary water treatment
    Deionization
    Demineralization
    pH control
    Hardness control
Water storage

Escalation--Costs during construction includes the following:

Increase in equipment costs between start of construction and equipment delivery
Increase in labor rate during construction period

Land cost--Includes the following cost:

Fees
Property
Surveys

Site preparation--(Included in plant facilities in Bureau evaluations.) Labor and material cost for the following:

Site clearing
Grading
Drainage
Excavation
Piling
Roads
    Access
    On-site
Walkways
Railroads
Fences
Parking areas
Other paved areas
Wharves and piers
Recreational facilities
Landscaping

Interest during construction period is as follows:

Interest on average amount of borrowed money for total plant cost

Working capital--Includes the following cost:

Raw materials and supplies
Product and in-process inventory
Accounts receivable
Available cash

Capitalized startup cost--Includes the following cost:

Plant modifications during startup

APPENDIX C.--ITEMS INCLUDED IN OPERATING COST COMPONENTS

Maintenance--Maintenance is divided into labor and material components. Labor as follows: Pipe fitters, electricians, welders, etc. Materials are as follows: Replacement parts, nuts, bolts, gaskets, welding rods, oxygen, acetylene, etc., used in repair.

Payroll overhead--Includes the following:

- Federal O.A.S.I.
- Worker's compensation coverage
- Contributions to pension, life insurance, etc.
- Vacation, holidays, sick leave, overtime premium
- Company contributions of profit sharing

Operating supplies--Includes the following cost:

- Lubricating oil
- Instrument charts
- Wiping cloths
- Filter cloth
- Gasoline and/or diesel fuel

Indirect cost*--Plant overhead which includes the following:

- Administration (plant supervision)
- Indirect labor
  - Laboratory
  - Technical service and engineering
  - Shops and repair facilities
  - Shipping departments
- Purchasing, receiving, and warehousing
- Personnel and industrial relations
- Inspection, safety, and fire protection
- Accounting, clerical, and stenographic
- Communications
  - Telephone
  - Mail
  - Teletype
- Plant office custodial and plant protection
- Medical and dispensary
- Cafeteria and clubroom
- Recreational activities
- Local contributions and memberships
- Waste disposal
- Control laboratories
- Storage facilities
- Salvage
- General engineering

*Company administrative and research and development costs outside the plant are <u>not</u> included here

Taxes--Property taxes

Insurance--Includes the following:

Liability
Property

Depreciation--Straight line--average for buildings and equipment

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